

Dawn/Dusk Dropouts due to Storms/Substorms Near the Outer Radiation Belt: Observations from CRRES

30 September 1999

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Prepared for

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2430 E. El Segundo Boulevard
Los Angeles Air Force Base, CA 90245

Engineering and Technology Group

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20000201 064

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. F04701-93-C-0094 with the Space and Missile Systems Center, 2430 E. El Segundo Blvd., Los Angeles Air Force Base, CA 90245. It was reviewed and approved for The Aerospace Corporation by A. B. Christensen, Principal Director, Space and Environment Technology Center. Michael Zambrana was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

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A handwritten signature in cursive script, reading "Michael Zambrana", is written over a horizontal line.

Michael Zambrana
SMC/AXE

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 30 September 1999	3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Dawn/Dusk Dropouts due to Storms/Substorms Near the Outer Radiation Belt: Observations from CRRES			5. FUNDING NUMBERS F04701-93-C-0094	
6. AUTHOR(S) C. G. Moukis, A. Korth, and R. H. W. Friedel				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The Aerospace Corporation Technology Operations El Segundo, CA 90245-4691			8. PERFORMING ORGANIZATION REPORT NUMBER TR-99(8570)-5	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Space and Missile Systems Center Air Force Materiel Command 2430 E. El Segundo Boulevard Los Angeles Air Force Base, CA 90245			10. SPONSORING/MONITORING AGENCY REPORT NUMBER SMC-TR-99-30	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) <p>We investigate the particle dropout events from the dawn flank of the magnetosphere as observed from a variety of instruments on board the CRRES satellite. All dropouts are observed at magnetic latitudes more than 10° above the magnetic equator. Plasma and energetic electron and ion data help us establish the boundary regimes being sampled. During these events, the magnetic field shows a dramatic change in the field line configuration from a dipole-like to a highly stretched tail-like. The LLBL moved to geosynchronous altitudes, and at times, the magnetospheric lobe is sampled. We conclude that they are associated with sub-storm growth phase stretching of the geomagnetic field during periods of intense storm activity.</p>				
14. SUBJECT TERMS Magnetosphere, CRRES			15. NUMBER OF PAGES 4	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT	

Acknowledgments

LEPA data were provided by A. Johnston of MSSl. The GOES magnetometer data were provided by NOAA. Provisional Dst and AE were provided by the World Data Center C2, Kyoto. The Los Alamos data were provided by D. Belian and G. Reeves. The authors wish to thank J. Woch and M. Thomsen for helpful discussions.

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1. Introduction

Energetic particle dropouts have been observed at geosynchronous orbit and have been associated with magnetopause crossings during disturbed geomagnetic conditions for the case of dayside sector dropouts [Korth *et al.*, 1982], or with the growth phase of substorms for dropouts observed near midnight [Baker and McPherron, 1990].

Another, more rare, class of dropout phenomena has been associated with the entry of geosynchronous spacecraft into the magnetospheric lobes. Thomsen *et al.* [1994] studied the frequency of occurrence and the local time dependence of the magnetospheric lobe regions at geosynchronous orbit using observations from the Los Alamos magnetospheric plasma analyzers (MPA). They found that there is a strong tendency for these lobe encounters to occur postmidnight, and as late as 0700 local time. They concluded that these dawn events are probably not due to substorm-growth-phase stretching of the geomagnetic field but are the result of major, probably asymmetric modifications of the magnetospheric field geometry in times of strong magnetospheric disturbances. Moldwin *et al.* [1995] concluded that the substorm growth phase picture cannot adequately explain these events. They proposed that the flank-lobe events are due to a major reconfiguration of the magnetosphere during large geomagnetic storms which are triggered by the passage of a large solar wind disturbance.

Kopanyi and Korth [1995] reported on energetic particle dropouts that were observed in the local morning sector with the geostationary satellite GEOS-2. These events occurred during magnetic storms and were associated with the recovery phase of a previous substorm in a multiple-substorm scenario.

Korth *et al.* [1994] using CRRES measurements studied a multiple dropout event from the dawn-flank of the magnetosphere during a large geomagnetic storm. They used energetic particle and magnetic field measurements, from CRRES, and they proposed that a strong field aligned current system together with the storm-enhanced ring current caused the compression of the local plasma sheet. This compression put the CRRES spacecraft outside the plasma sheet and into the lobe region.

In a statistical study of the dropout events observed by CRRES, Fennell *et al.* [1996] found that the majority of the flank plasma dropout events occurred as the satellite crossed (or was crossed by) the boundary between the plasma sheet and tail lobe as was evidenced by the passage of the Region 1 current system along with the strongly tail-like field geometry.

In this study we investigate particle dropout events, occurring at the dawn flank of the magnetosphere during disturbed geomagnetic conditions, using observations from a series of instruments on board the CRRES satellite. Events are classified as particle dropouts only when fluxes drop to background levels across a wide energy range, from a few hundred eV to 1.2 MeV [Fennell *et al.*, 1996]. Here we extend on the study of the dawn flank dropout event presented by Korth *et al.* [1994]. The inclusion of plasma electron and ion data helped us identify the boundaries crossed during the dropout events. Furthermore, GOES-6 magnetometer and LANL energetic particle observations provided an overview of the global state of the magnetosphere.

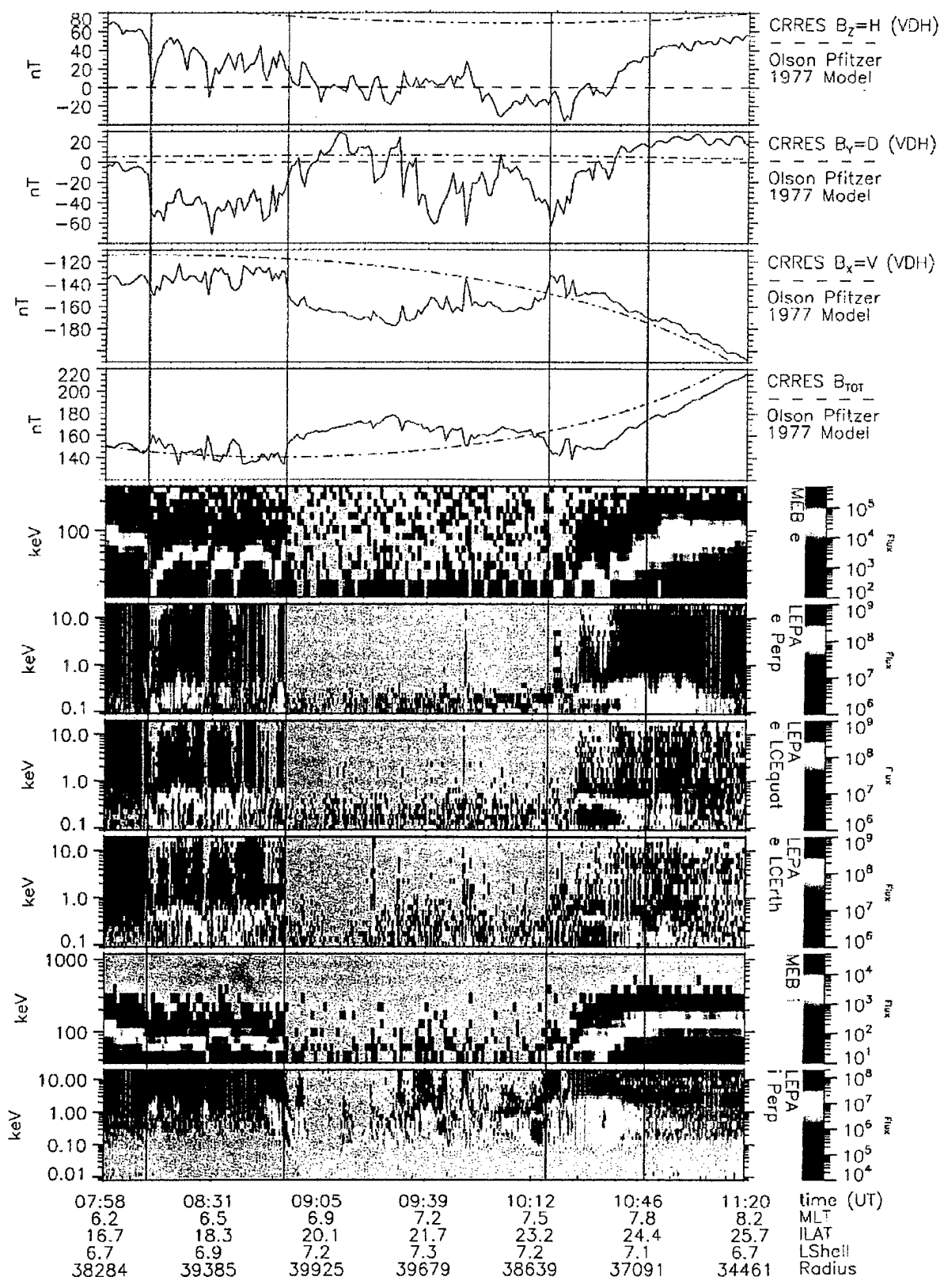
2. Mission and Instrumentation

The Combined Release and Radiation Effects Satellite (CRRES) had an elliptical, 18.1° inclination orbit, and covered the regions up to L=8, at magnetic latitudes mostly within 20° of the magnetic equator. In this study we use data from two particle spectrometers, LEPA and MEB, and the magnetic field instrument [Singer *et al.*, 1992]. The Low Energy Particle Analyzer (LEPA) [Hardy, 1993] measures electrons and ions (no composition) in the energy range from 100 eV to 28 keV. The Medium Electron B Spectrometer (MEB) [Korth *et al.* 1992] covers electrons from 21 keV to 285 keV and total ions (no composition) from 37 keV to 3.2 MeV.

3. Observations

3.1. CRRES observations

Plate 1 displays data from the orbit 69, 23 August 1990 event. Apogee was at ~0700 MLT and the magnetic latitude at apogee was 21°. The upper four panels, (numbered 1 to 4), show the three magnetic field components in the VDH coordinate system together with the total magnetic field. At dawn, D is positive in the sunward direction. Dashed lines indicate the zero-nT line for the components and the dashed-dotted line the calculated values from the Olson-Pfizer-1977-Model. The next four panels show electron energy spectra from the MEB instrument at 90° pitch angle (panel 5), and from the LEPA instrument in the perpendicular (panel 6), equatorward (field aligned fluxes coming from the equator, panel 7) and Earthward (field aligned fluxes coming from the Earth, panel 8) look directions. The last two panels show the MEB (panel 9) and LEPA (panel 10) energy spectra for 90° pitch angle ions.



In Plate 1, five major regions are identified, marked by Latin numbers I to V. At 0813 UT CRRES is coming out of the plasma sheet (region I) and enters a region (region II) characterized by very high fluxes of balanced bi-directional field aligned low energy (up to 500 eV) electrons (panels 7,8) and by the presence of almost isotropic fluxes of energetic (up to 50 keV) electrons and ions (panels 5,9). Another characteristic of this region is the mixing of plasma sheet ions with a population of 500 eV to a few keV ion fluxes (panel 10) of, most probably, heated magnetosheath ions. The presence of energetic trapped particles with flux levels near those in the neighboring magnetosphere is an indicator that this region is the LLBL on closed field lines [Lotko and Sonnerup, 1995]. In this region the D-component of the magnetic field has a pronounced tailward direction. During this period, three small duration dropouts are observed at 0813 UT, 0830 UT and 0848 UT. These events are accompanied by decreases to small or even zero values of the H-component of the magnetic field.

At 0854 UT CRRES enters a region (region III) where energetic ions and electrons (panels 5,9) drop out for a long time period (~ 1 hour). Furthermore, low energy electrons are depleted although high intensity bursts of 100 - 500 eV electrons reappear sporadically (most probably due to the movement of the boundary the satellite returns in the previously probed region). However, the main characteristic of this region is the presence of very intense fluxes of magnetosheath type 100 eV to 1 keV ions (panel 10). We believe that during this period CRRES is probing the LLBL on open field lines [Fujimoto *et al.*, 1998]. The absence of low energy electrons (panel 6) must be due to the lower energy threshold of the instrument (100 eV). There are also intervals in which low energy ions are completely depleted. These intervals are identified as regions of open field lines in the magnetospheric lobe [Thomsen *et al.*, 1994].

At the same time the magnetic field configuration changes dramatically. The H component of the magnetic field decreases to small and even negative values while the V component increases to high negative values. Hence, the magnetic field configuration has developed into a stretched, tail-like, configuration with the one end on open field lines. The D component fluctuates between positive (sunward) and negative (tailward) values probably because of the sunward/tailward flow of the magnetosheath-like cold ions [Fujimoto *et al.*, 1998]. The total magnetic field increases to values higher than the Olson-Pfizer-1977-model values. This excess magnetic pressure compensates for the defect in plasma pressure caused by the absence of energetic magnetospheric particles [Sonnerup *et al.*, 1992].

The three short duration dropouts observed in region II have the characteristics of this open field line region and were caused by the spatial movement of the boundary relative to the satellite.

At 1017 UT CRRES returns into the LLBL on closed field lines (region IV). Although, during this period, the H-component of the magnetic field takes high negative values (-40 nT) the presence of energetic trapped populations and bi-directional field aligned low energy electrons indicates that CRRES stayed within the magnetosphere.

At 1048 UT CRRES enters the plasma sheet and ring current region (region V).

Besides the dawn-flank events we also investigated dusk-flank events (not shown). These events showed similar characteristics as in the dawn side. We found no evidence of a dawn-dusk asymmetry.

3.2. Complementary observations

AE and Dst indices (not shown) show that these dropout events occurred during the recovery phase of an intense storm. The onset of the storm happened two days earlier and the minimum Dst value was -97 nT. Continuous substorm activity during the storm recovery phase kept Dst depressed for several days [Korth *et al.*, this issue]. The AE index rose to ~1700 nT marking the time of the substorm onset. Energetic electron data from the Los Alamos geosynchronous satellite 1987-097 (not shown) indicate no crossing of the magnetopause on the dayside. At local midnight energetic electron data from the Los Alamos satellite 1989-046 (not shown) show a substorm injection at ~1000 UT, verifying the AE onset signature. Magnetometer data from GOES-6 satellite (not shown) show a stretched, tail like, magnetosphere. This stretching starts at ~0800 UT (2300 LT) the time when CRRES finds itself suddenly in the LLBL on closed field lines (region II) and ends at ~1000 UT (0100 LT). The subsequent dipolarisation coincides with the substorm injection observed by the LANL satellite and also with the end of the dropout event as seen by CRRES on the dawn side. The dropout period is thus clearly associated with a substorm growth phase and formation of a stretched field line configuration.

4. Discussion and Conclusions

Due to its elliptical orbit, CRRES spent long time periods (~ hours) skimming local boundaries at apogee during disturbed times. During this particular event CRRES was probing the LLBL and the lobe for almost two hours.

These observations have been consistent with reports that during southward turnings of the IMF B_z , the LLBL is partially on closed and partially on open field lines [Lotko and Sonnerup, 1995; Fujimoto *et al.*, 1998]. However, in this paper results were obtained on the flanks deep inside the magnetosphere near geosynchronous altitudes. The inclusion in this study of the plasma electron and ion data allowed us to distinguish between the LLBL on open and closed field lines and the lobe region.

The presence of the very intense field aligned low energy electron fluxes at the LLBL on closed field lines is consistent with Region 1 field aligned currents that flow into the ionosphere [Iijima and Potemra, 1976] suggesting that the source of these currents is the LLBL. The presence of this current system explains the tailward deviation of the D component of the magnetic field (region II).

The simultaneous observations from the three different satellites (CRRES, LANL and GOES) allowed us to link the local observations of CRRES with the global behavior of the magnetosphere. The very disturbed geomagnetic conditions (as indicated by the Dst index) resulted in the compression/erosion of the flank side of the magnetosphere. The LLBL and lobe boundaries moved down to geosynchronous altitudes due to the substorm-growth-phase stretching of the magnetosphere during a storm time period and the subsequent thinning of the plasma sheet. Most of the dropouts observed can be associated with substorm growth phase during disturbed times.

In conclusion, we have seen that the dawn flank of the magnetosphere is highly dynamic during disturbed geomagnetic conditions. During a storm, plasma sheet thinning related to substorm growth phase stretching can be extended up to the flanks of the magnetosphere. Because of this reconfiguration of the magnetosphere the lobe together with the LLBL (on closed and open field lines) can be observed down geosynchronous altitudes at the dawn flank of the magnetosphere.

References

- Baker, D. N., and R. L. McPherron, Extreme energetic particle decreases near geostationary orbit: A manifestation of current diversion within the inner plasma sheet, *J. Geophys. Res.*, 95, 6591, 1990.
- Fennell, J. F., J. Roeder, H. Spence, H. Singer, A. Korth, M. Grande and A. Vampola, CRRES observations of particle flux dropout events, *Adv. Space Res.*, 18, 217, 1996.
- Fujimoto, M., T. Mukai, H. Kawano, M. Nakamura, A. Nishida, Y. Saito, T. Yamamoto, and S. Kokubun, Structure of the low-latitude boundary layer: A case study with Geotail data, *J. Geophys. Res.*, 103, 2297, 1998.
- Hardy, D., Low energy plasma analyzer (LEPA) on CRRES, *Nucl. Inst. and Methods*, 1993.
- Iijima, T., and T. A. Potemra, The Amplitude Distribution of Field-Aligned Currents at Northern High Latitudes Observed by Triad, *J. Geophys. Res.*, 81, 2165, 1976.
- Kopanyi, V., and A. Korth, Energetic particle dropouts observed in the morning sector by the geostationary satellite GEOS-2, *Geophys. Res. Lett.*, 22, 73, 1995.
- Korth, A., G. Kremser, P. W. Daly, and E. Amata, Observations of field-aligned energetic electron and ion distributions near the magnetopause at geosynchronous orbit, *J. Geophys. Res.*, 87, 10,413, 1982.
- Korth, A., G. Kremser, B. Wilken, W. Guttler, S. L. Ullaland, and R. Koga, Electron and proton wide-angle spectrometer (EPAS) on the CRRES spacecraft, *J. of Spacecraft and Rockets*, 29, 609, 1992.
- Korth, A., R. Friedel, D. N. Baker, H. Luhr, S. L. Ullaland, J. F. Fennell, and G. D. Reeves, Dynamics of the plasma sheet in the dawn sector of the magnetosphere: Observations from CRRES, *Proceedings of ICS-2*, 1994.
- Korth, A., R. H. W. Friedel, C. Mouikis, and J. F. Fennell, Storm/Substorm Signatures in the Outer Radiation Belt, *Proceedings of ICS4*, this issue.
- Lotko, W., and B. U. Ö. Sonnerup, The Low-Latitude Boundary Layer on Closed Field Lines, in *Physics of the Magnetopause*, *Geophys. Monogr. Ser.*, vol. 90, edited by P. Song *et al.*, AGU, Washington, D. C., 1995.
- Moldwin, M. B., M. F. Thomsen, S. J. Bame, D. J. McComas, J. Birn, G. D. Reeves, R. Nemzek, and R. D. Belian, Flux dropouts of plasma and energetic particles at geosynchronous orbit during large geomagnetic storms: Entry into the lobes, *J. Geophys. Res.*, 100, 8031, 1995.
- Singer, H. J., W. P. Sullivan, P. Anderson, F. Mozer, P. Harvey, J. Wygant, W. McNeil, Fluxgate magnetometer instrument on the CRRES, *J. Spacecraft and Rockets*, 29, 599, 1992.
- Thomsen, M. F., S. J. Bame, D. J. McComas, M. B. Moldwin, and K. R. Moore, The magnetospheric lobe at geosynchronous orbit, *J. Geophys. Res.*, 99, 17283, 1994.
- Sonnerup, B., G. Paschmann, T.-D. Phan, and H. Lühr, Magnetic field maxima in the low latitude boundary layer, *Geophys. Res. Lett.*, 19, 1727, 1992.